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ART. XXI.—*Weathering of the "Older Basalt" of Royal Park.*

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1. Introduction.

The olivine basalt occurring in the Royal Park area belongs to a series of volcanic rocks extruded in the Lower Kainozoic era, and known to Victorian geologists as "The Older Basalts," to distinguish them from the "Newer Basalts" of Newer Kainozoic and Recent times.

The "Older Basalts" are widespread in Victoria, occurring at Royal Park, North Melbourne, Kensington, Essendon, Broadmeadows, Keilor, Bacchus Marsh, Berwick, Curlewis, French Island, Phillip Island, Flinders, and Cape Schanck. In South Gippsland they occur at Leongatha, Neerim, Mirboo, &c., and in North Gippsland they cap the highly dissected plateau at elevations of 5,000 to 6,000 feet, as at Mt. Hotham, Mt. Fainter, the Bogong High Plains, and the Dargo High Plains.

At Royal Park, in the railway cutting, the older basalt is seen underlying marine Tertiaries, which have been referred by Chapman⁽¹⁾ to the Barwonian (Janjukian). At Sutton-street, a short distance south of Flemington Bridge Station, the basalt rests on the eroded surface of the Lower Tertiary leaf beds, which, however, do not appear in the railway cutting. In other parts of the Royal Park area, the Tertiary sands rest directly upon the Silurian rocks, without the interposition of the older basalt.

2. Exposures at Royal Park.

The outcrop in the railway cutting consists of a very much weathered basalt, with fresh samples existing only in the cores of spheroidal nodules, which persist here and there in the more decomposed material.

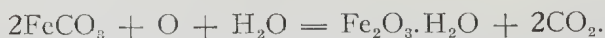
In the south-eastern wall of the cutting, it occurs as a dark crumbly material, containing nodules of fresher basalt, showing spheroidal laminae, or "onion structure." This material consists of a streaky and mottled clay substance, the streaks being due to specks of oxides of iron in the lighter coloured argillaceous substance, formed by decomposition of the original felspars in the basalt.

On the same side of the cutting, further south, the weathering has produced segregated masses of iron oxides, which contain apparently little or no siliceous material. This probably contains much of the iron which has been leached out of the bleached weathered basalt close by. The chemical changes involved in this segregation of iron are as follows:—Surface waters containing carbonic acid, and, perhaps, other organic acids, dissolve

the iron contained in minerals such as olivine. The solutions of iron, in the form of iron bicarbonate, are converted into iron carbonate, carbon dioxide, and water, thus:—



Further oxidation of this iron carbonate produces a hydrated iron oxide, goëthite, thus:—



This iron is eventually deposited as limonite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$).

At the southern end of the north-western wall of the cutting the basalt appears as a hummocky-shaped mass of whitish clay, the lower part containing spheroidal nodules surrounded by well developed concentric laminae of more weathered basalt. This clay merges into the chocolate-coloured surface soil. Further north, along the cutting, it underlies Tertiary fossiliferous iron-stained sands. In the hollows of the basalt the lowest member of the Tertiary sands occurs as thin bedded white sands, which underlie the fossiliferous band. Through the clay run thin veins, about $\frac{1}{4}$ inch thick, consisting of a fine white clay-like material; these evidently occupy the position of joint planes in the basalt. The upper portion of the basalt outcrop here is remarkable for the intense leaching which has taken place. This leaching appears to be local, for it is absent in neighbouring outcrops in the district. Another small outcrop, showing concentric weathering, occurs in the Royal Park, inside the gate in Flemington-road, about 200 yards from the corner of Gatehouse-street. Other outcrops occur at Spencer-street and North Melbourne railway stations, at Sheil-street "Quarries," North Melbourne, at Kensington, at Ascot Vale, and at Essendon.

From the outcrop in the north-western wall of the railway cutting, samples were taken for chemical analyses. Near the base of the wall, a large nodule was exposed, being about 18 inches long, and surrounded by well-developed concentric laminae of weathered rock. Its interior was unaltered, and has been analysed as a representative sample of the fresh basalt. Near the outside of the fresh core, there is a sudden change from fresh grey basalt to a red iron-stained concentric band, about $\frac{1}{2}$ inch thick. This band is nearly as hard as the fresh basalt, and is not detached at all from it. Outside this is a semi-detached concentric layer of light-brownish crumbly rock, from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch in thickness. Then occur successive fawny-coloured layers, each semi-detached from the previous one, the layers becoming softer and lighter in colour, as they get further from the core, until they merge into a soft, whitish, incoherent, argillaceous substance, the last stage of decomposition of the basalt. This residual clay has a kaolin-like appearance, and its chemical composition shows a certain resemblance to that of kaolin, but it contains 2.56 per cent. of alkalis (including 1.66

per cent. of potash), and the resulting soil is fertile. The greater part of the lime, magnesia, and soda has been carried away, as well as most of the iron, the little remaining being in the ferric condition. That the decomposition of this basalt has been from without, and not from within, is confirmed by microscopic examination of the rock sections mentioned below.

Closely related to the decomposition of iron-bearing minerals in the basalt is the distribution of small rounded and irregular shaped pellets of ironstone in the Tertiary sands, which overlie the basalt in the Royal Park area. These pellets ("Buck-shot Gravel") vary in size from minute fragments up to pieces $\frac{3}{4}$ inch long. It is assumed that they are formed from solutions containing iron dissolved out of pre-existing rocks. These solutions, on coming in contact with oxygen, have their iron oxidized, and deposited on small particles of sand as nuclei, forming rounded pellets of limonite.

An interesting mode of formation of somewhat similar pellets is suggested by the manner of their occurrence in older basalt outcropping in the "Quarries," abutting on Sheil-street, near the gasometer. This outcrop is about $\frac{3}{4}$ mile south of Royal Park. On the surface soil here was an abundance of the pellets, and their source was found close by in very decomposed vesicular basalt. In nearly every vesicle was one of the pellets, exactly the shape of the vesicle, and completely filling it. These pellets are therefore more regular in shape than those of the buck-shot gravel found in the Tertiary sands at Royal Park. This vesicular basalt was very much bleached and decomposed, and apparently had suffered a great deal of alteration before the deposition of limonite in its vesicles. The following types of decomposition products of the basalt occur at the "Quarries":—

- (1) Vesicular basalt, very much decomposed, and some of it containing amygdaloides of limonite.
- (2) Normal basalt, less decomposed than the latter.
- (3) Spheroidal cores of weathered basalt. A microscopic section of one showed it to be an olivine basalt similar to that at the railway cutting, but not so fresh, and containing much more magnetite.
- (4) Concretions of hematite and limonite, the structure showing cores often quite detached from the outer concentric shells.
- (5) Segregated lumps of magnesite.
- (6) A greyish waxy substance showing thin streaks of limonite, and films, along cracks, of what appears to be black oxide of manganese. Its appearance suggested halloysite, and the following chemical analysis was made. Comparison of it with the theoretical

composition of halloysite, and with an analysis of halloysite from Silesia,⁽³⁾ suggests that part of the theoretical alumina may be replaced by iron.

TABLE I.

Substance from the "Quarries."					Halloysite from Silesia.	Theoretical Composition of Halloysite (Dana).
SiO ₃	43.38	..	..	..	42.00	43.5
Al ₂ O ₃	17.37	..	..	..	20.12	36.9
Fe ₂ O ₃	13.81	..	..	..	8.53	
H ₂ O (-)	8.26	17.89	..	..	24.00	19.6
H ₂ O (+)	9.63					
MgO	4.13	..	..	..	2.01	
CaO	1.61	..	..	..	2.81	
Na ₂ O	0.54	0.87	..	..	0.50	
K ₂ O	0.33					
CO ₂	nil					
MnO	0.05					
Total	99.11	..	..	..	99.97	100.0

3. Chemical Analyses.

The following analyses were made to determine the chemical changes which have taken place in the various stages of the decomposition of the Royal Park basalt:—

- I. *Fresh Basalt*, from the interior of the large nodule described above. A portion of the nodule was broken into pieces the size of small marbles and carefully sampled in order to get a fairly representative analysis of the fresh rock.
- II. *Decomposed Basalt*, selected at a distance of 2 inches laterally from the solid core. It consisted of crumbly concentric layers, about $\frac{1}{8}$ inch in thickness, and soft enough to be easily broken between thumb and finger. It was quite unlike the dark-grey fresh basalt, its colour being pale yellowish to brown.
- III. *More-decomposed Basalt*, selected at a distance of 12 inches laterally from the core. This was somewhat similar in appearance to the previous sample, being lighter in colour, but softer and more easily broken.
- IV. *Residual Clay*, selected at a distance of 6 feet above the nodule. It consisted of a whitish argillaceous material, quite unlike basalt, having lost all concentric structure showing in the less decomposed rock. A few feet above the source of this sample the clay merged into the brown surface soil.

V. *Vein Substance*, existing in the residual clay, in the position of joint planes of the original basalt.

TABLE II.

	Fresh Basalt.	Decomposed Basalt.	More Decomposed Basalt.	Residual Clay.	Vein Substance.
	I.	II.	III.	IV.	V.
SiO ₂ ..	45·64	43·74	39·09	43·82	43·97
Al ₂ O ₃ ..	14·35	19·20	19·74	28·76	30·08
Fe ₂ O ₃ ..	2·08	11·57	15·57	2·66	2·39
					(Total iron)
FeO ..	10·32	0·65	0·46	0·20	..
MgO ..	9·50	0·94	1·05	0·03	0·38
CaO ..	7·87	2·03	0·49	0·58	0·26
Na ₂ O ..	2·17	2·00	2·03	0·90	1·37
K ₂ O ..	1·23	1·86	1·80	1·66	2·44
H ₂ O (—) ..	1·92	8·56	7·30	7·56	5·63
H ₂ O (+) ..	1·29	5·43	8·11	9·23	10·31
CO ₂ ..	0·47	0·04	0·09	0·04	0·04
TiO ₂ ..	2·74	3·60	3·62	4·75	4·21
P ₂ O ₅ ..	0·42	n.d.	n.d.	0·05	n.d.
SO ₃ ..	nil	..	..	n.d.	..
Cl ..	0·02	..	..	..	..
S ..	0·14	..	..	..	..
Cr ₂ O ₃ ..	0·01	..	..	..	..
V ₂ O ₅ ..	0·05	..	..	..	..
MnO ..	0·13	..	..	..	..
BaO ..	nil	..	..	..	..
SrO ..	0·02	..	..	..	..
ZrO ₂ ..	0·03	..	..	..	..
Totals ..	100·40	99·62	99·35	100·24	101·08

Analyst, D. M. McCance.

The Norms and Classification of the fresh basalt, based on the above analysis, are as follows:—

NORMS.

Orthoclase ..	7·23
Albite ..	18·34
Anorthite ..	25·85
Diopside ..	8·56
Hypersthene ..	13·22
Olvine ..	13·98
Magnetite ..	3·02
Ilmenite ..	5·17
Pyrite ..	0·24
Apatite ..	0·93

CLASSIFICATION.

Class	III.	..	Solfemane
Order	5	..	Perfelie : Gallare
Rang	4	..	Docalcie : Auvergnase
Sub-rang	4-5	..	Presodie : Auvergnose

In comparing the ultimate composition of the decomposed stages of the basalt with that of the fresh rock, as indicated by the above analyses, one may note the following:—In the first

stage of decomposition (Col. II.), there is a slight loss of silica and soda, a considerable loss of lime, an almost total loss of magnesia and carbon dioxide, a slight increase in potash, a great increase in alumina, in titanium, and in hydration, and a considerable oxidation of ferrous iron to the ferric state with practically no loss in the total iron content.

In the more decomposed stage (Col. III.), there is a further loss of silica, an almost complete loss of lime, an increase in the total iron, with further oxidation of the small amount of ferrous iron left in the previous stage, and a smaller increase in hydration, while the alkalies, magnesia, titanium, and carbon dioxide are about the same as in the previous stage.

In the residual clay stage (Col. IV.), the silica shows an increase over the previous stage, being only slightly less than in the fresh rock. Soda suffers a marked loss, while potash shows a slight loss, but is still in excess over the potash in the fresh rock. Magnesia, lime, carbon, and phosphorus have practically gone. There is a slight increase in hydration, an increase in titanium, and a very marked increase in alumina.

G. P. Merrill⁽²⁾ has pointed out (p. 187) that the indicated loss or gain of any constituent may be only apparent, and the relative proportions can be learned only by calculating results on a common basis. He adopts a method in which one rock constituent is assumed to be constant, and the other constituents are compared with it. Either ferric oxide or alumina is taken as invariable, and using it as a standard the relative losses of the other constituents can be roughly estimated.

Following this method, the above analyses have been recalculated to a total of 100.00, on a hygroscopic water-free basis, assuming alumina as constant (Table III.).

This treatment of the analyses makes the silica of the residual clay show a gain of 0.94 per cent., whereas, on the figures of the original analysis, it appeared to lose 1.82 per cent. But this is only an apparent gain; for the alumina, which is assumed constant, shows an increase from 14.75 per cent. to 31.03 per cent. This great increase of alumina and of titania points to a concentration of these in the clay. If we calculate what would be the percentage of silica, assuming that the alumina remains constant at 14.75 per cent., we find that there is actually a loss of 23.87 per cent. of silica. Similarly titania and potash, instead of gaining, actually lose 0.34 per cent. and 0.40 per cent. respectively.

The calculations of losses, &c., shown in the following table are made on the following formulæ given by Merrill⁽²⁾ (p. 188):—The "percentage of entire rock lost" in the clay is the percentage of each constituent in the fresh

rock minus the percentage of the same constituent in clay multiplied by $\frac{\text{the percentage of alumina in the fresh rock}}{\text{the percentage of alumina in the clay}}$.

The "percentage of each constituent retained" is the $\frac{\text{percentage of it in clay}}{\text{percentage of it in fresh}} \times \frac{\text{percentage of alumina in fresh rock}}{\text{percentage of alumina in clay}} \times 100$.

The "percentage of each constituent lost" is 100—percentage of it retained. For example, the percentage of entire rock lost in the case of silica is $46.34 - 47.28 \times \frac{14.75}{31.03} = 23.87$ per cent.

That is, in the residual clay there has been a loss of 23.87 of the 46.34 per cent. of silica contained in the fresh basalt. This represents a loss of 51.51 per cent. of the original silica, while the percentage of silica retained is $100 - 51.51$, or 48.49 per cent.

The residual clay has the general appearance of kaolin, and the analysis indicates that it consists mostly of hydrous silicates of alumina. The leaching out of most of the iron (89.25 per cent. lost) accounts for its bleached look. The 9.96 per cent. content of H_2O (+) indicates combined water, and is an actual gain in substance. The titanium has been mostly retained, only 12.28 per cent. of it being lost. 79.04 per cent. of the soda and 31.92 per cent. of the potash have disappeared. Over 95 per cent. of the phosphorus, carbon dioxide, lime, and magnesia have gone, the last-named being practically absent. This great loss of magnesia (99.85 per cent.) is very noticeable, even in the partially decomposed stage (Col. XI., Table III.). This is due to the breaking down of the abundant olivine present.

Merrill⁽²⁾ (p. 206) quotes analyses of fresh and decomposed basalt from the Haute Loire, France, by Ebelman. The losses calculated on analysis of the residual clay of Royal Park agree very closely with those of the Haute Loire basalt, except that the Royal Park basalt lost 96.26 per cent. of the lime, whereas the Haute Loire basalt lost only 47 per cent. of the lime.

In passing outwards from the fresh rock there is a gradual decrease in the percentage of each constituent retained. An exception to this, however is the iron. The percentage of iron retained in sample II., 2 inches from the core, is 68.68 per cent. (Col. VIII., Table III.), but in sample III., 12 inches from the core, there remains a greater percentage, 87.36 per cent. The residual clay retains only 10.75 per cent. of iron. Probably some of the dissolved iron was re-deposited further out from the core. Magnesia and carbon dioxide also increase slightly in sample III. compared with sample II., so possibly some of the iron and magnesia are re-deposited as carbonates. Further out, in the clay, the iron and the magnesia have suffered very great loss (Col. XIII.).

TABLE III.
CALCULATED LOSS OF MATERIAL IN DECOMPOSED OLIVINE BASALT OF ROYAL PARK.

	Analyses of Fresh and Decomposed Rock Re-calculated to Total of 100·00 and Hygroscopic Water-free.				Percentage of Entire Rock Lost.			Percentage of Each Constituent Lost.			Percentage of Each Constituent Retained.			Remarks.
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	
	Fresh Basalt.	Partially Decomposed.	More Decomposed.	Residual Clay.	Part Decomp.	More Decomp.	Resid. Clay.	Part Decomp.	More Decomp.	Resid. Clay.	Part Decomp.	More Decomp.	Resid. Clay.	
SiO ₂ ..	46·34	48·04	42·47	47·28	12·74	17·14	23·87	27·40	36·98	51·51	72·51	63·02	48·49	(Constant)
Al ₂ O ₃ ..	14·75	21·09	21·45	31·03	0·00	0·00	0·00	0·00	0·00	0·00	100·00	100·00	100·00	
Fe ₂ O ₃ ..	2·11	12·71	16·91	2·87	4·31	1·74	12·27	31·32	12·64	89·25	68·68	87·36	10·75	
FeO ..	10·48	0·71	0·50	0·22	..	..	..	..	..	..	..	..	..
MgO ..	9·65	1·03	1·14	0·03	8·93	8·87	9·64	92·53	91·87	99·85	7·47	8·13	0·15	
CaO ..	8·01	2·23	0·53	0·63	6·45	7·65	7·71	80·53	95·45	96·26	19·47	4·55	3·74	Actual gain
Na ₂ O ..	2·20	2·20	2·21	0·97	0·66	0·68	1·74	30·05	30·92	79·04	69·95	69·08	20·96	
K ₂ O ..	1·25	2·04	1·95	1·79	(gain) -0·18	(gain) -0·09	0·40	0·00	0·00	31·92	100·00	100·00	68·08	
H ₂ O (+) ..	1·31	5·96	8·81	9·96	(gain) -2·86	(gain) -4·75	-3·43	0·00	0·00	0·00	100·00	100·00	100·00	
CO ₂ ..	0·48	0·04	0·10	0·04	0·45	0·41	0·46	94·17	85·67	96·04	5·83	14·33	3·96	
TiO ₂ ..	2·78	3·95	3·93	5·13	0·02	0·08	0·34	0·60	2·77	12·28	99·40	97·23	87·72	
P ₂ O ₅ ..	0·43	n.d.	n.d.	0·05	..	..	0·46	..	..	95·05	..	..	4·95
V ₂ O ₅ ..	0·05	..	..	..	..	..	..	..	..	..	..	..	..
Cl ..	0·02	..	..	n.d.	..	..	..	..	..	..	..	..	..
S ..	0·14	..	..	..	..	..	..	..	..	..	..	..	..
Total ..	100·00	100·00	100·00	100·00	
Total Loss of Original Material					33·56%	36·57%	56·89%							

NOTE.—Al₂O₃ in fresh rock includes ZrO₂ 0·03%, Cr₂O₃ 0·01%, and MnO 0·13%. They were not determined in decomposed rock.

4. Summary of Results of Analyses.

In the above table, Columns VIII., IX., and X., which give the respective percentages of each constituent lost, are very illuminating. In the partially decomposed stage (Col. II.) it will be noted that the silica appears to be in greater amount than in the fresh rock (Col. I.), but the above method of calculating losses shows this apparent increase of silica to be really a loss of 12.74 per cent. of the entire rock (Col. V.), equivalent to loss of 27.49 per cent. of the original silica in the fresh rock (Col. VIII.). Similarly, in the more decomposed stage (Col. III.), the silica appears to have decreased slightly from 46.34 per cent. to 42.47 per cent., but actually the loss is much greater, being a loss of 17.14 per cent. of the entire rock (Col. VI.), and a loss of 36.98 per cent. of the silica originally present in the fresh rock (Col. IX.) In the residual clay (Col. IV.), the silica shows an apparent slight increase, but in reality the clay has lost 51.51 per cent. of the original silica (Col. X.). These figures show a progressive increase in the percentages of silica lost in the three stages of decomposition, viz., 27.49 per cent., 36.98 per cent., and 51.51 per cent. respectively, and indicate the progressive breaking down of the silicate minerals—feldspars, olivine, and augite.

Magnesia shows the greatest losses, viz., 92.53 per cent., 91.87 per cent., and 99.85 per cent. in the three stages of decay respectively. The great loss in the partially decomposed rock (92.53 per cent.), is evidently due to the early decay of the olivine, and the carrying away of the magnesia in solution.

Lime is nearly equal to magnesia in the large percentages lost. In the three stages it shows a progressive loss, viz., 80.53 per cent., 95.45 per cent., and 96.26 per cent. respectively, of the lime originally present. The great loss in the partially decomposed stage is no doubt due to the early breaking up of the soda-lime feldspars. The residual clay retains only 3.74 per cent. of the original lime, this retained portion probably existing in small grains of undecomposed augite.

Carbon dioxide shows an equivalent loss with lime and magnesia in its percentage losses of 94.17 per cent., 85.67 per cent., and 96.04 per cent. respectively. As Column VIII. shows that most of it disappears in the partially decomposed stage, it indicates the early removal of any carbonates present, viz., secondary calcite and magnesite.

Phosphorus also suffers almost complete loss in the residual clay, in which only 4.95 per cent. is retained. Its presence indicates the occurrence in the rock of minute apatite crystals, although none is seen in the microscopic rock sections examined.

The Alkalies suffer great losses, the soda in much greater proportion than the potash. The losses for soda are 30.05 per cent., 30.92 per cent., and 79.04 per cent. in the three stages respectively. The bulk of this will be due to decomposition of the soda-lime feldspars, and the removal of the soda in solution. The losses in the first two stages are less than expected, but this indicates that undecomposed feldspar is present. Even in the residual clay, which loses 79.04 per cent. of soda, there must still be small fragments of the unaltered feldspar. The potash appears to gain slightly in the first two stages (Cols. V. and VI.), but this is possibly due to errors in analysis. This retention of potash is due to the presence of small shreds of biotite, which are seen under the microscope. This biotite may eventually disintegrate, but is relatively stable to decay in basic igneous rocks. Possibly some of the potash is contained in feldspar, for potash feldspars are known to be more stable than soda-lime feldspars. In the residual clay, there is still 68.08 per cent. of the original potash retained.

Titanium, some of which is probably contained in the augites, as these show a pale purplish tint with transmitted light, is apparently in a very stable form, because in the residual clay only 12.28 per cent. of it is lost. Some of the titanium in this clay may exist in small unaltered augites. It is more probable, however, that it exists mostly in ilmenite, which is very resistant to atmospheric agencies. The rock contains a good deal of magnetite, but it is impossible to distinguish this from the ilmenite in the sections examined.

Iron, estimated as Fe_2O_3 , has lost 89.25 per cent. in the clay. That remaining exists mostly in the ferric condition, excepting a small fraction in the ferrous condition in the residual magnetite or ilmenite (Col. IV.).

Combined water.—The progressive increase of this with advancing decomposition is evident from the figures in the table. The actual gain is due, of course, to the formation of hydrated minerals.

Alumina, although it has been assumed constant, exists in the clay in quite a different form from that in the fresh rock. In the latter, it occurs in the form of anhydrous silicates of alumina, soda, lime, magnesia, and iron, such as feldspar, augite, and biotite; but in the clay a great proportion of it exists as a hydrous silicate of alumina (kaolin).

On the whole, there has been a very decided loss of material in each of the decomposed stages. The partially decomposed stage shows a total loss of 33.56 per cent. of the original rock (Col. V.). The more decomposed stage loses altogether 36.57 per cent. (Col. VI.), and the residual clay loses a total of 56.89 per cent. of the entire rock material (Col. VII.).

5. Petrological Description of the "Older Basalt."

The "Older Basalt" has been previously described by Skeats⁽⁴⁾ as a "medium grained ophitic olivine-basalt, with large olivine phenocrysts, brown irregular augites, magnetite, lath-shaped plagioclase, and a little residual interstitial felspar of a more acid character, and which may be in part orthoclase."

Although the basalt is very much decomposed, it is possible to obtain remarkably fresh samples from the interior of spheroidal nodules, which are distributed among the more decomposed rock.

The fresh rock is of a dark grey colour, and its texture is fine-grained, compact, and homogeneous. It has a density of 2.89. It is holo-crystalline, and macroscopically it shows numerous amygdalae of carbonate of iron, up to a diameter of about $\frac{1}{4}$ of an inch. This carbonate occurs in the freshest parts of the rock. It is evidently cavity-filling, and was deposited probably during the late stages of crystallisation. Under the microscope it is porphyritic, with abundant phenocrysts of very fresh olivine. The finer ground mass consists of lath-shaped plagioclase, with pale mauve-tinted augite ophitic round the felspars, and contains abundant grains of magnetite.

The plagioclase laths consist largely of basic labradorite with lamellar twinning, and showing extinction angles up to 38° . The laths are clear and fresh, and show trachytic texture. There is also some interstitial felspar which is more acid than the laths, being of lower refractive index than they, but higher than the balsam. It is andesine or oligoclase.

The olivine is remarkably fresh, plentiful, and idiomorphic, with rectangular and rhombic cross sections. It is clear, colourless, and traversed by rough cleavage cracks, and shows alteration to calcite and serpentine along the cracks.

Green and yellowish-green serpentine replaces part of the olivine. In one example there occurs a large, roughly octagonal piece of serpentine with a wavy extinction, and showing a dark cross with crossed nicols under low power.

Magnetite is abundant in square, rectangular, irregular, and spindle shapes. The elongated shapes suggest its being ilmenite in part. Many small grains are included in the olivines.

Biotite is present in a few small brown shreds of basal section, showing no pleochroism.

Amygdalae of secondary carbonate occur through the basalt. These are light brownish in colour; under the microscope they are nearly colourless, with a pale creamy tint. This carbonate shows characteristic rhombohedral cleavages, and is surrounded

by a narrow rim of green or yellow serpentine. Chemical tests showed it to consist mostly of carbonate of iron, with a small amount of lime.

In the fresh basalt, near the outside of the core, the serpentine loses its green colour, becoming discoloured yellow to brown, due to the deposition of hydrated iron oxides. The olivine which remains looks just as fresh as that in the interior of the core.

In a section of decomposed basalt, taken from the outer shell of the core, there is a sharp line of demarcation between the fresh rock and a red band of more decomposed rock, which forms the outside of the more solid core. In this section the olivines are much decomposed along their edges and along the cleavage cracks, being replaced by brilliant red and brown oxides of iron, and by serpentine. In some cases the olivine is thus wholly replaced.

A section of the first shell of still more decomposed basalt, which is separated from the solid core along a concentric joint crack, is yellowish to red on account of deposition of iron. Not much olivine is left, it being mostly replaced by iron oxides and serpentine. Serpentine occurs interstitially, in large amount, and coloured from yellowish green to orange. The augites and feldspars look fresh, except for a slight iron staining in places. Magnetite has been deposited along a crack in the rock, concentric with the core.

A section from the centre of a boulder from the Sheil-street "Quarries" shows it to be a basalt similar to the one in the railway cutting. Magnetite is in greater abundance.

6. Summary.

G. P. Merrill⁽²⁾ (p. 221), has pointed out that the silicates which are most readily decomposed are those containing protoxides of iron and manganese, or lime, and that the first indication of the decomposition is signalled by a ferruginous discoloration and the appearance of calcite.

This observation is applicable to the Royal Park basalt. Here, the first evidence of decay is the deposition of serpentine and calcite along the cracks of the olivine, while a later stage shows the iron discoloration, accompanied by the gradual disappearance of the olivine.

The freshest samples show phenocrysts of clear olivine, traversed by rough cleavage cracks, and frequently showing prismatic forms of pinacoids and domes with acute terminations. Edges are usually rounded and corroded.

The augites, in small prismatic crystals, the lath-shaped plagioclases, and the magnetite appear quite fresh. The pale mauve tint of the augites suggests the presence of titanium.

The amygdales, which consist of carbonates of iron and calcium, are of magmatic origin, because, apart from a little interstitial serpentine among the feldspars, there is no other sign of decomposition in the freshest samples.

The olivine is the first mineral to show any change, this being the formation of thin deposits of serpentine and calcite along the cleavage cracks. In more decomposed samples this serpentinisation spreads, becomes iron-stained, and forms a meshed framework of the original crystal shape, leaving only "islands" of undecomposed olivine. Very often there is a rough outline of the original olivine crystal, consisting wholly of a mass of hydrated iron oxides.

The extraction of iron from the fresh rock by solution is shown by a reddish band forming as a crust on the outside of the otherwise fresh nodule. In one example there is a sharp line of demarcation separating the fresh rock from the reddish band. In this band, the identity of many of the original crystals, especially olivine, is masked by the deposited iron oxides. The augites and feldspars become iron-stained, and iron is deposited as grains of magnetite along the cracks between concentric laminae.

The chemical analysis of the decomposed stage a little further out, 2 inches from the core, showed that the iron present was mostly in the ferric condition, viz., 12.71 per cent. of ferric iron, and only 0.71 per cent. of ferrous iron (Table III., Col. II). This indicates the breaking up of the iron-bearing minerals, and the oxidation of most of the ferrous iron, of which the fresh rock contains 10.48 per cent. The little ferrous iron remaining at this stage is that contained in undecomposed magnetite or ilmenite. Under the microscope the residual clay shows a multitude of minute grains of magnetite and probably ilmenite, since a great number of them are spindle shaped.

It is probable that a physical analysis of the residual clay would give additional information concerning the nature of undecomposed minerals remaining in the clay.

All the evidence indicates that the decomposition of this basalt has been caused by infiltration of solutions from without the rock, assisted largely by the natural spheroidal jointing of the basalt. The most weathered portions are found nearest the outside, the fresh rock being found only in the interior of boulders occurring among the more decomposed material.

The greater loss of soda than of potash shown in the analyses, is in accord with the investigations of Merrill and of others quoted by him (p. 222). The comparatively small loss of potash here (31.92 per cent.) indicates the greater stability of the potash feldspars which lose little by decomposition, but become converted into fine silt by a mechanical splitting up, as Merrill has described.

The analysis of vein substance taken from a joint plane in the residual clay (Table II., Col. V.) was made in order to find out whether it might be due to an accumulation of carbonates of lime and magnesia, deposited from solutions passing along the joint planes. The analysis, however, proves that the substance does not differ very much in chemical composition from that of the residual clay. It contains less lime and iron, and a very little more magnesia. It shows about 1 per cent. more alkalies, but this may be an error in the analysis, because of the high summation in the figures of the analysis, viz., 101.08.

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